LOCO IN THE ALBA STORAGE RING

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Abstract

ALBA is a 3 GeV 3rd generation light source which achieved first stored beam in March 2011 and was commissioned from March to June 2011 [1]. The ring comprises of 112 independent quadrupoles grouped in 14 families and 32 combined gradient dipoles powered in series. This paper reviews the process of recovering the design lattice and the symmetry of the machine. The main tool employed for this has been the LOCO implementation provided in the Matlab MiddleLayer. First results shows that the main effect on the symmetry is the difference among bending magnets. As this effect can not be compensated locally at present at the bendings, a global optics correction using all the quadrupoles is used.

INTRODUCTION

Figure 1 shows one of the four superperiods. The ring consists of 16 sectors: 8 unit cells and 8 matching cells [2]. Each unit cell accommodates 8 BPMs, 6 quadrupoles and 2 gradient dipoles, while each matching cell has 7 BPMs, 8 quadrupoles and 2 gradient dipoles.

The ratio of the number of magnets over the BPMs is larger than one, 112 quadrupoles plus 32 gradient dipoles over 120 BPMs. This has an important impact on the LOCO analysis. In addition, during this phase of the commissioning the number of BPMs equipped with the acquisition electronics was reduced to 104, removing one BPM per sector, because 16 Libera modules were needed for diagnostics tests.

Over the three months of commissioning, the correction of the linear optics was an iterative process carried out with the optimization of closed orbit distortion and beam based alignment [3] and the adjustment of the RF frequency. Preliminary tests with LOCO at ALBA were already performed for the ALBA booster to detect calibration errors in the magnets [4]. In the storage ring, LOCO has been used with two purposes: first, calibrating the parameters of the model, especially the gradient dipoles, and then, correcting the optics to recover the symmetry of the machine with the 112 individually powered quadrupoles.

A test to measure the effect of the insertion devices (the multiple wiggler and the two in-vacuum Apple II undulators) was also performed with LOCO and the first results of the tune shifts and the beta beating calculated with LOCO agree with the theoretical ones [5].

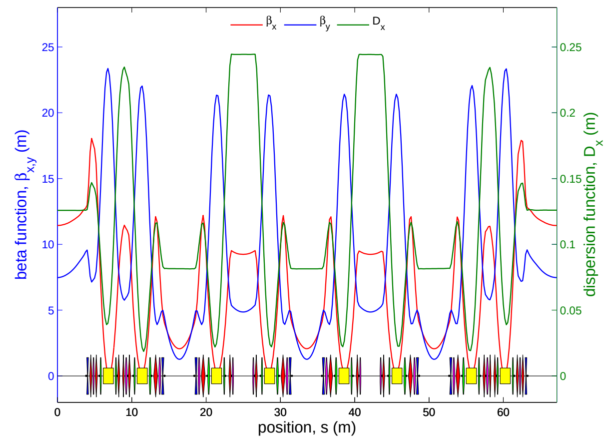

Figure 1: ALBA optical functions for one of the 4 superperiods.

DATA SETS FOR THE LOCO ANALYSIS

The standard set of input data for a LOCO analysis comprises a measured dispersion function, a BPM noise measurements and an orbit response matrix.

Typical rms BPM noise data are acquired at 2 Hz rate during 180 seconds and gave values of 600 nm horizontal and 350 nm vertical (for difference orbits with respect to the previous). The dispersion function is measured by varying the RF frequency by ± 250 Hz, corresponding to an orbit distortion of ± 140 μm. The orbit response matrix is measured with a bipolar change in the correctors to produce an orbit distortion of ± 300 μm. For 88 horizontal and 88 vertical correctors magnets, the total measurement takes about 15 minutes.

Table 1: Parameters used by LOCO to fit the model response matrix to the measured one.

Parameter type	Number of elements
BPM gains (hor. + vert.)	208
BPM coupling factors	208
Corrector strengths (hor. + vert.)	176
Corrector coupling	176
Quadrupole gradients	112
Dipole gradients	32

LOCO ANALYSIS

The minimization method used to fit the data was the scaled Levenberg-Marquard [6].

The changes to the quadrupole settings applied to symmetrize the optics were calculated fitting the horizontal dispersion and the uncoupled response matrix with a scaling constant lambda [6] of 0.001 and a number of singular values of 300 over 668 parameters (rejection threshold 10^{-4}). This changes were effective to correct the optics but had the inconvenience of large drifting up to 4% in two families of adjacent quadrupoles whose variations compensate each other.

A more detailed analysis of the data, taken in the last shifts before the summer shutdown, has showed that a better correction, with good χ^2 and minimized quadrupole changes within 1%, can be achieved with higher lambda equal to 0.1 and more singular values, 580 over 668 (rejection threshold 10^{-6}, see Fig. 2). This optimization must be implemented and confirmed on the machine in the next run of October 2011.

Finally, a coupled analysis, including the off-diagonal matrix blocks and the vertical dispersion and adjusting the BPM and corrector coupling factors, was performed.

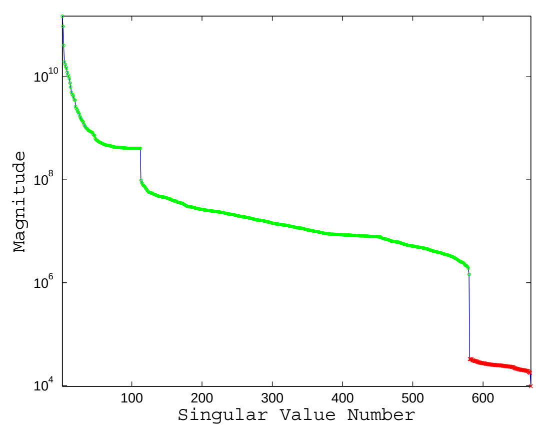

Figure 2: Spectrum of the singular values for the uncoupled LOCO fit with rejection threshold 10^{-6}: retained values are shown in green, rejected in red.

LOCO RESULTS: CALIBRATIONS

Calibration of the dipole gradients

The main result of the analysis of the response matrix with LOCO was the correction of the calibration of the dipole gradients by -0.28% on average, with respect to the value estimated from the magnetic measurements (Fig. 3). This explains the missing vertical focusing found in the measured vertical tune, that was lower by 0.12 with respect to the expected from the model.

While the k value of the dipoles rescaled by -0.28% was included in the model, random errors generated by the dipole gradients can not be corrected locally, since all the bendings share the same power supply. A global symmetrization was then performed using only the quadrupoles all around the ring.

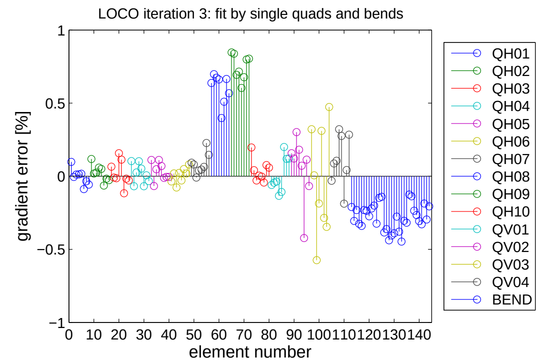

Figure 3: Calibration errors in the 112 quadrupole and 32 gradient dipoles fitted by LOCO.

Calibration of the quadrupole gradients

The calibrations of the quadrupoles have been confirmed by the LOCO analysis with errors within 0.1% as in the magnetic measurements, except two quadrupole families, QH08 and QH09, beside the short straight sections that were miscalibrated by +0.7% (Fig. 3). The k value of QH08 and QH09 corrected by +0.7% was included in the model.

Calibration and coupling of the BPMs

Calibration of the BPMs were fitted by LOCO and they were found scaled on average by +1% horizontal and -2% vertical (Fig. 4). Analysis of the coupled matrix and vertical dispersion has given a BPM rms coupling factor of 1.5% (that can be due to mechanical roll, non linear response and cross talk of the BPM channels). Tests including the gain and coupling fitted by LOCO will be performed in the next run to improve the correction of the orbit and the measurement of the vertical dispersion.

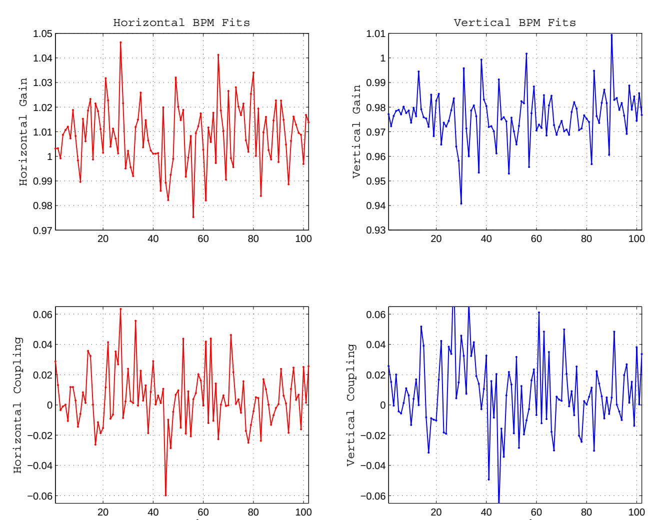

Figure 4: BPM gains (top) and coupling factors (bottom) in the horizontal (red) and vertical plane (blue).

LOCO RESULTS: OPTICS CORRECTION

The correction of the symmetry was performed fitting the response matrix with the 112 individually powered quadrupoles. Correction of the dispersion was very easy (Fig. 5). The fitted quadrupole settings converged to stable values after 3 iterations and the measured beta-beating was reduced from 30% to 2% in both planes (Fig. 6).

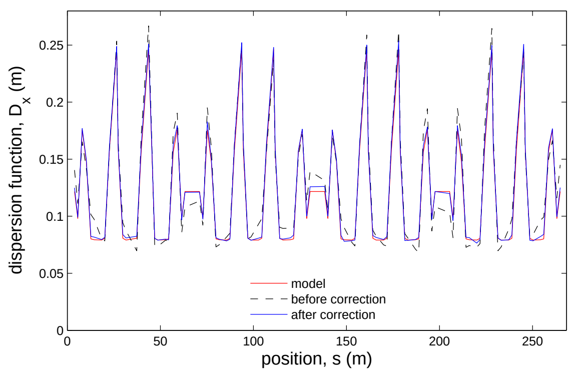

Figure 5: Horizontal dispersion function before (black) and after (blue) the LOCO symmetrization: the last iteration is very close to the model (red).

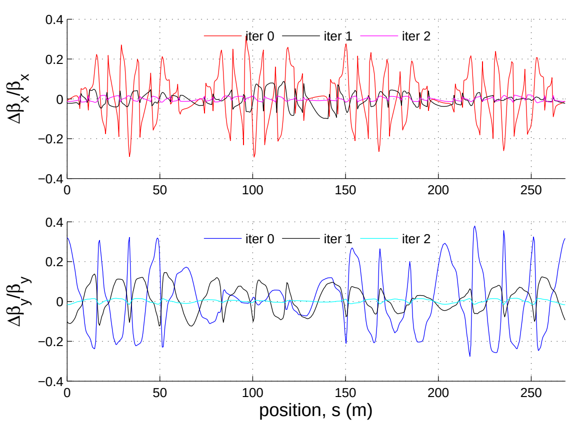

Figure 6: The horizontal (top) and vertical (bottom) beta beating in two symmetrizations of the optics is corrected from 30% (peak-to-peak) to 2% in both planes.

The total quadrupole changes applied to symmetrize the machine are within 1%, except the doublet of focusing quadrupoles QH03 and QH04 of the matching sections without BPM in between, where the changes are fighting each other and have drifted up to 4% (Fig. 7).

After reanalysing the data, we have realized that these large changes will be avoided increasing the scaling constant lambda of the minimization method to 0.1.

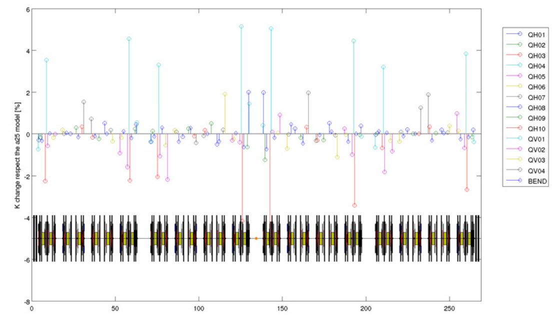

Figure 7: Total quadrupole gradient corrections applied to the storage ring to symmetrize the optics. Variations are within 1%, except the doublet of focusing quadrupoles QH03 and QH04 of the matching sections without BPM in between, where the changes are fighting each other and have drifted up to 4%.

FURTHER DEVELOPMENTS

The plan for the next storage ring start up consists in returning the quadrupoles to a common starting value within each family and symmetrizing the optics with changes fitted with a higher scaling constant lambda.

The following steps for the LOCO studies will be more investigations on the calibration of the dipole gradients iterated with optimization of the orbit and RF frequency and measurements, and correction of the effect of the insertion devices and of the coupling. Finally, the possibility of a local correction of the dipole gradients using the trim coils can be also studied.

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